

AN INVESTIGATION OF LOW EARTH ORBIT INTERNAL CHARGING

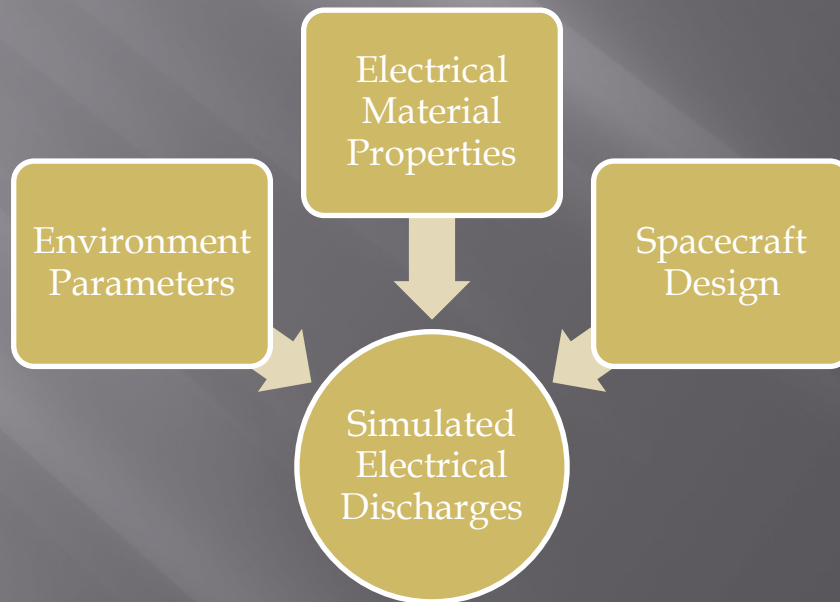
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13th SCTC, June 23-27, 2014

Overview

- ▣ Motivation
- ▣ Model development
 - Observations
 - Physics
 - Implementation
- ▣ Summary

Internal Charging Model (I.Cam)

- ▣ Motivation: To develop a tool that simulates electrical discharges due to internal charging in order to facilitate spacecraft design and anomaly investigations for programs



Model Parameters

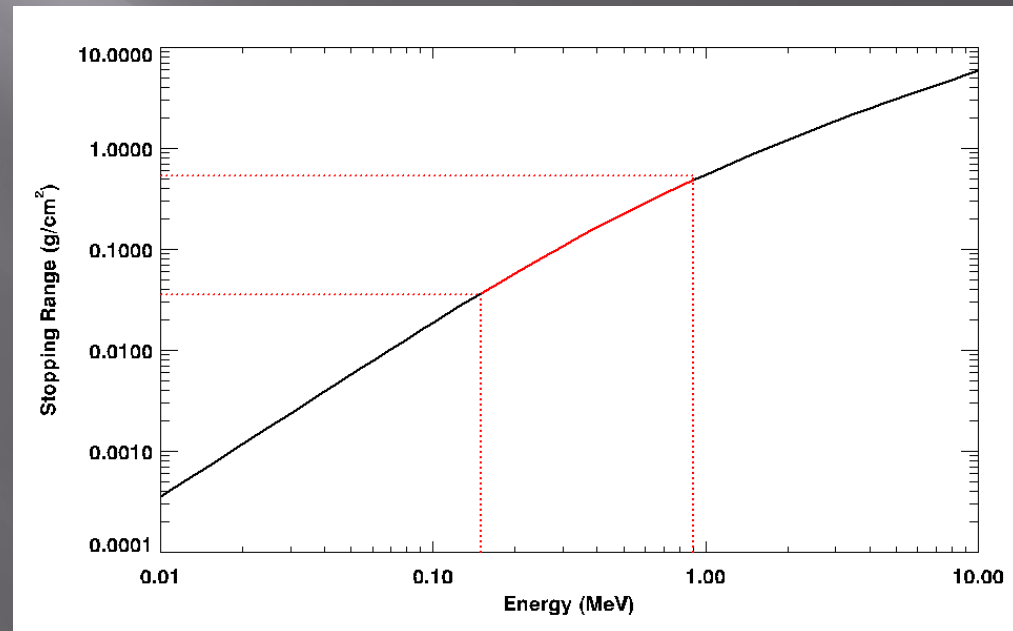
- ▣ Code supports LEO (both high and low inclination) internal charging investigations
- ▣ Model considers:
 - Insulators or ungrounded conductors under thin shielding
 - Various thicknesses of materials
 - Different material properties

Satellite Data

- ▣ NOAA 19 POES – MEPED particle sensor
 - Medium Energy Proton and Electron Detector
 - Three integral electron flux channels cover 30-1100 keV
 - ▣ > 30 keV, > 100 keV, > 300 keV
 - ▣ 0 and 90 degree look angles
- ▣ Model supports energies 20-900 keV
- ▣ 16s averaged data (instrument can provide observations at 2s resolution)
- ▣ Sun synchronous, 870 km 98.7° inclination
- ▣ Calculate current density

Calculation of penetration depth

- ▣ Need to know what fraction of the electron environment is being deposited in the material given a material thickness and density
- ▣ Used 10 layers of MLI and converted to areal density (g/cm^2)
- ▣ Used data from NIST ESTAR for continuous slowing down approximation to find energy range given a thickness



Equations

- ▣ Internal electric field calculation based on 1-D internal charging model (Garrett and Whittlesey, 2000)

$$\epsilon \frac{d\bar{E}}{dt} + \sigma \bar{E} = \bar{J}$$

- τ is the time constant for charge loss through conduction
 - J is the radiation source current density
 - Δt is time between observations
- ▣ Calculate current density (J) from NOAA-19 integral electron number flux data

Assumptions

- ▣ Amount of charge lost in discharge is random percentage of total charge
 - Max and min percentages are set
- ▣ Insulators have smaller discharges than conductors
- ▣ Uses 150 - 900 keV for penetration depth
- ▣ Adds bins for pitch angles 0 and 90
- ▣ Assume 3 discharge times to bound the parameters calculated for each discharge

Model

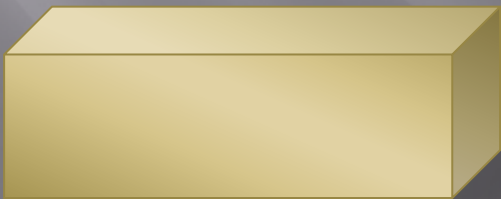
- ▣ For each point in time:
 - Calculate the internal electric field, potential, and stored charge
 - Calculate the enhanced electric field based on sharp points
 - Compare this new E to the breakdown strength of the material, if $E > \text{breakdown strength}$
 - ▣ Produce an arc based on a randomly generated amount between two prescribed values
 - ▣ Calculate potential, energy, charge before the arc
 - ▣ Calculate potential, E , energy, charge after the arc
 - ▣ Calculate energy and charge lost to arc and the current of the arc

Geometry case 1

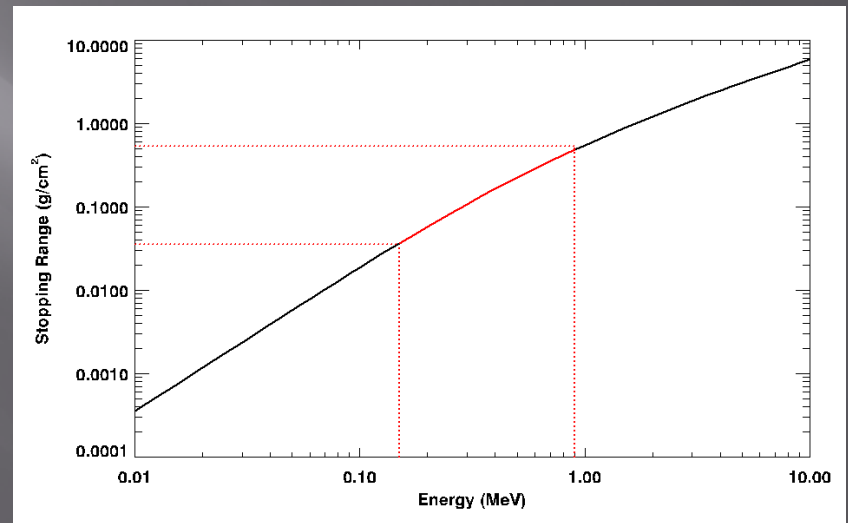
- ▣ Simulates 10 mil shielding
- ▣ 100 x 100 cm ungrounded conductor with a thickness of 5mm



10 mil MLI



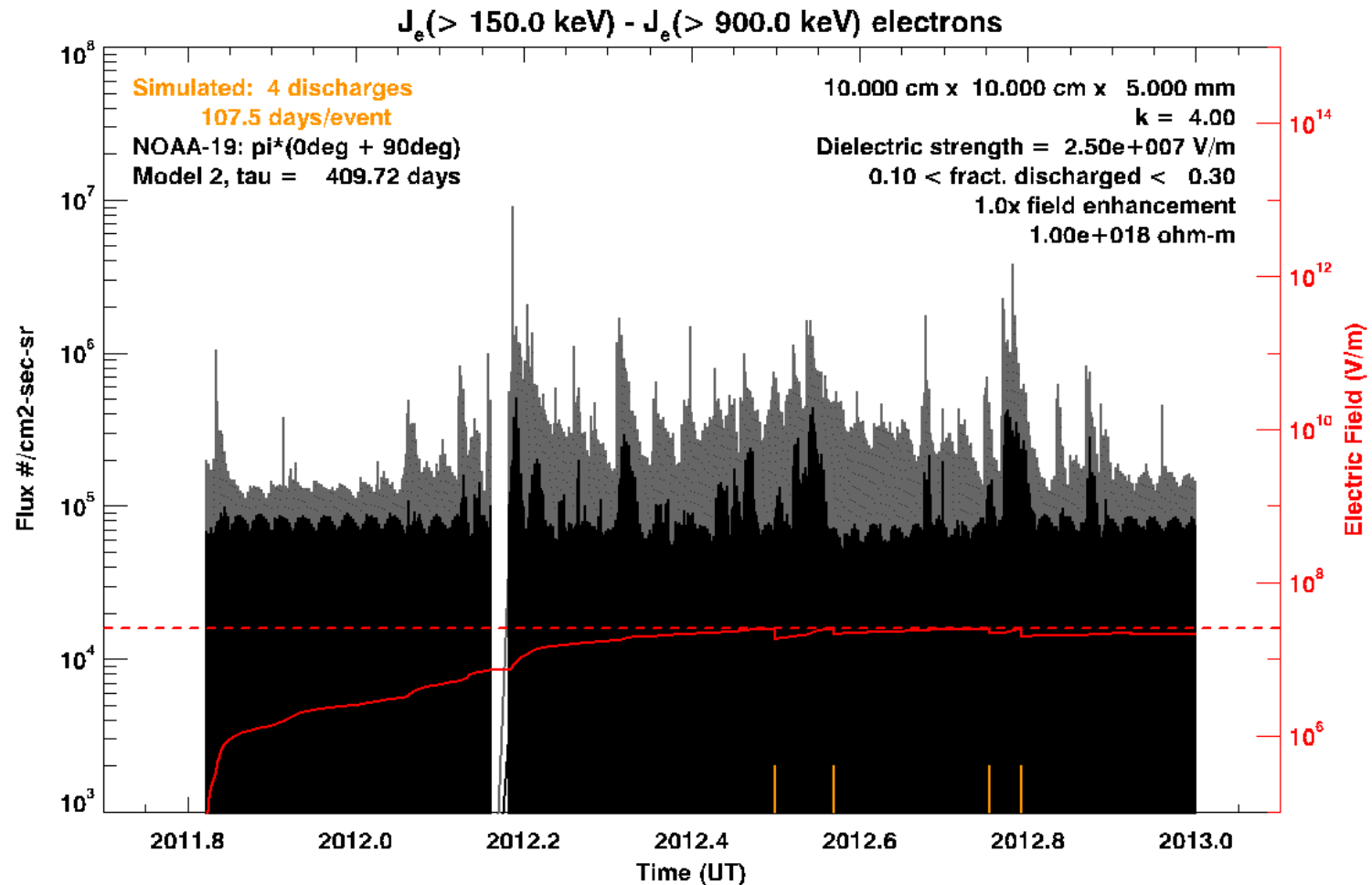
100 x 100 x 0.5 cm



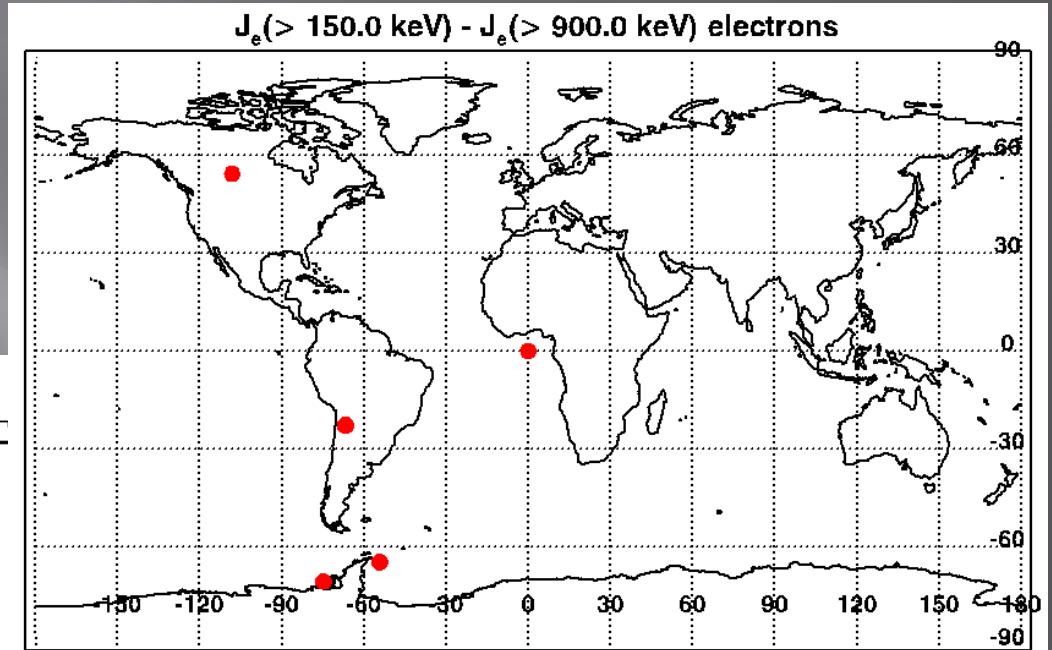
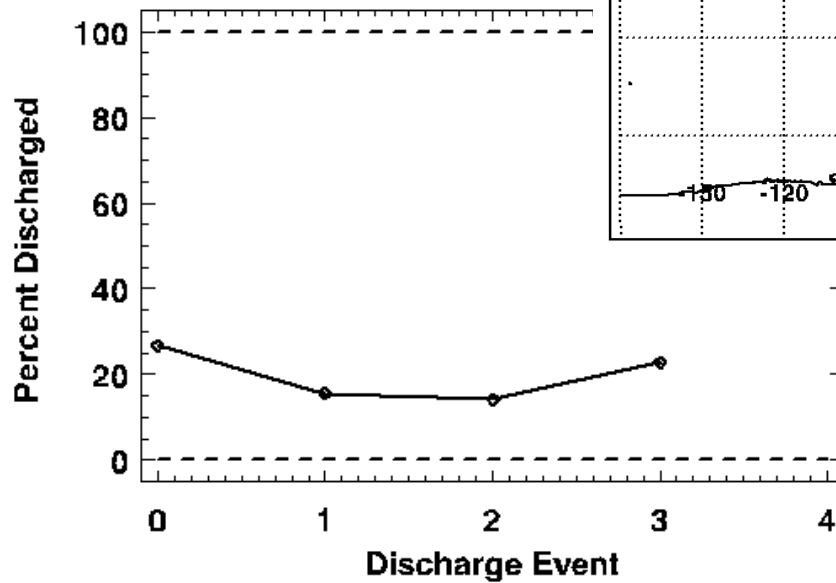
Parameters – Example 1

150. keV	threshold energy for electrons penetrating MLI
900. keV	maximum energy for electrons penetrating MLI
4.0	dielectric constant
5.0 mm	thickness of wire insulation
100. cm	length of exposed wire (cm)
100. cm	width of expose wire (cm)
$10^{18} \Omega \cdot m$	volume resistivity ($\Omega \cdot m$, $\rho = 1/\sigma$)
1.0	density (not currently implemented)
$10^{-14} / \Omega \cdot m$	radiation induced conductivity (RIC, not currently implemented)
$2.5 \times 10^7 \text{ V/m}$	breakdown strength
1.0	E-field enhancement factor (1=no enhancement, allow sharp points)
0.30	maximum discharge
0.10	minimum discharge
0.1 μ sec	discharge time A
1 μ sec	discharge time B
10 μ sec	discharge time C

Results (1)



Discharges (1)



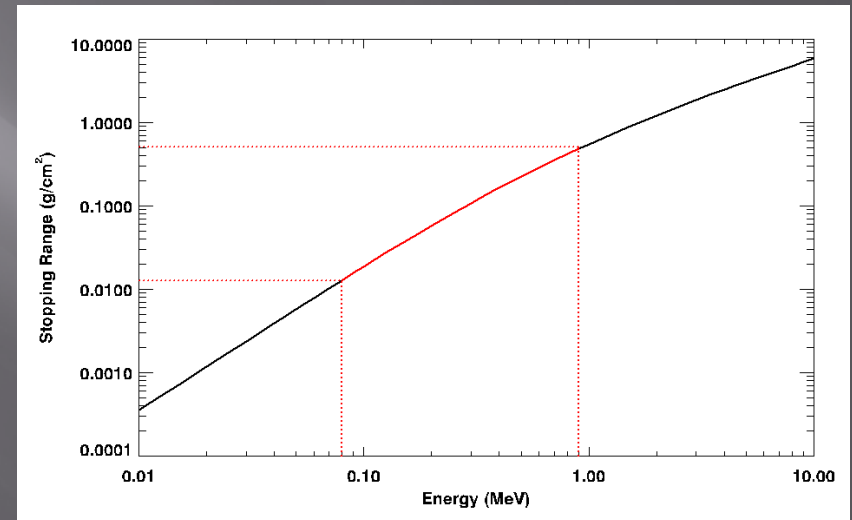
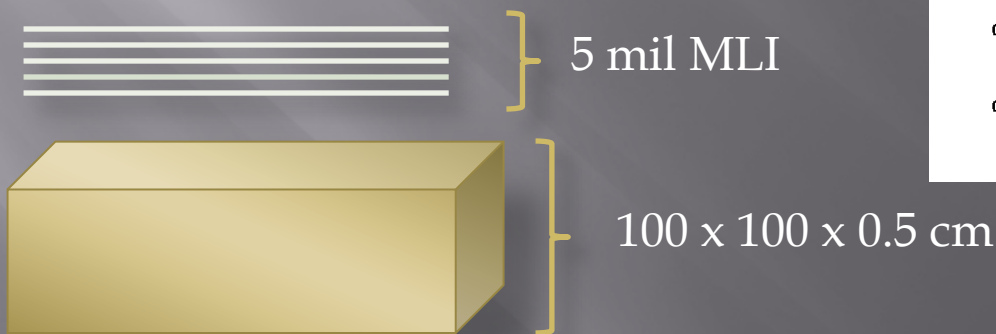
Summary (1)

Arc	Decimal Year (UT)	Day of Year (UT)	Fraction Discharged	Surface Voltage (volts)		Arc Energy (mJoule)	Arc Current (Amp)		
				Before arc	After arc		0.10 μ sec	1.00 μ sec	10.00 μ sec
0	2012.4995	183.8301	0.1515	125000.1	106058.5	15493.1982	1.34E+03	1.34E+02	1.34E+01
1	2012.5434	199.8988	0.1894	125003	101324.3	18971.375	1.68E+03	1.68E+02	1.68E+01
2	2012.655	240.742	0.2437	125000.2	94539.2	23673.375	2.16E+03	2.16E+02	2.16E+01
3	2012.7985	293.2561	0.2055	125000.5	99307.8	20401.3105	1.82E+03	1.82E+02	1.82E+01

Simulated: 4 discharges, 107.5 days/event

Geometry case 2

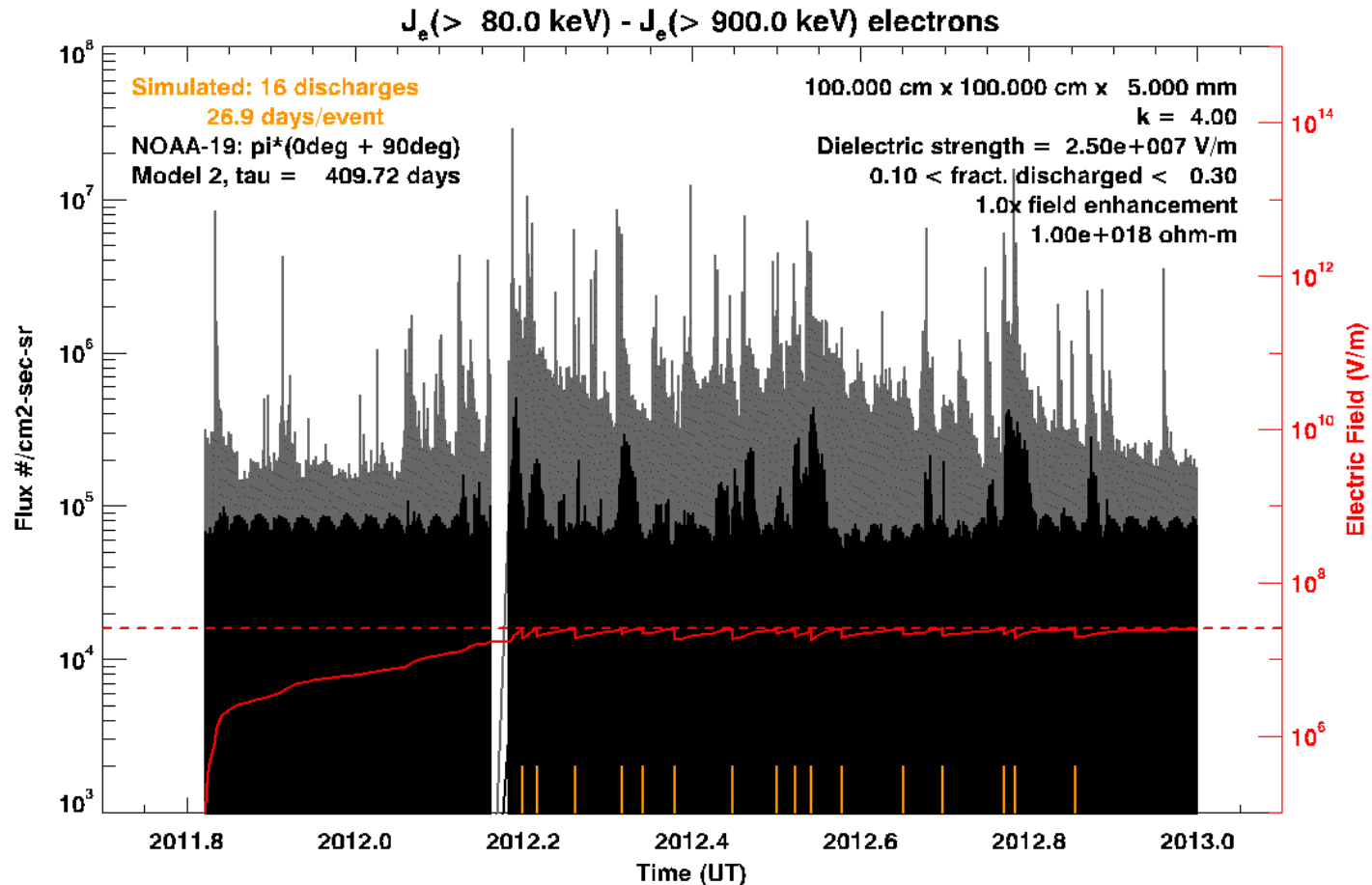
- ▣ Simulates 5 mil shielding
- ▣ 100 x 100 cm ungrounded conductor with a thickness of 5mm



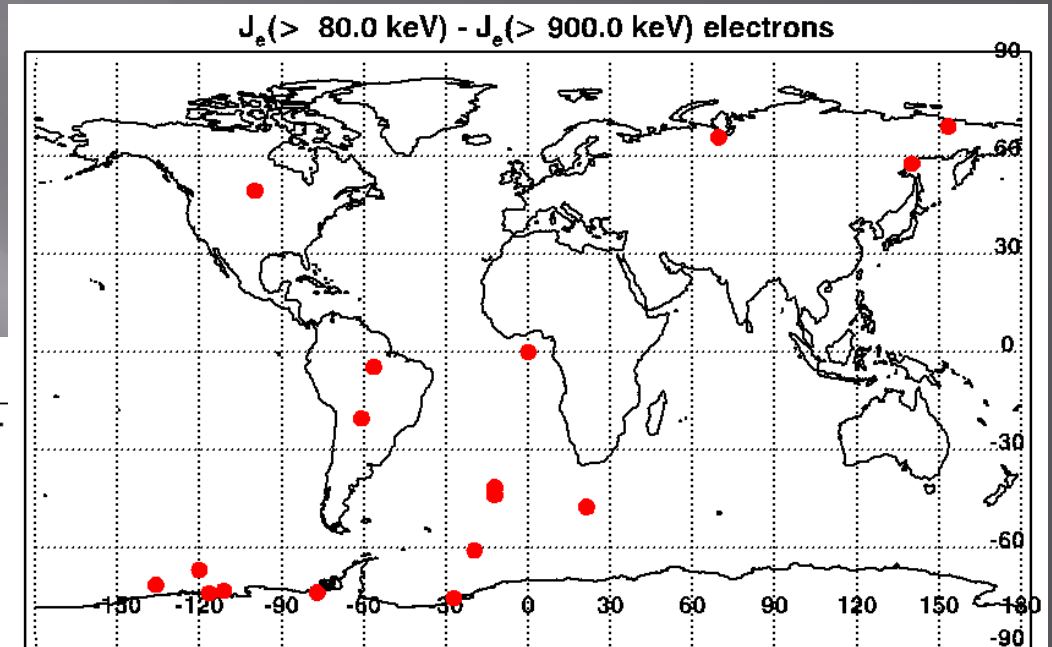
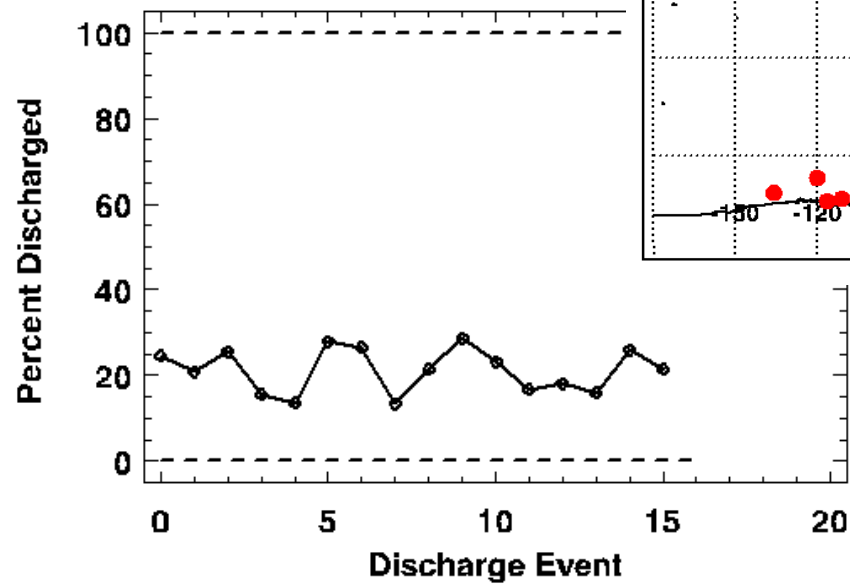
Parameters – Example 2

80. keV	threshold energy for electrons penetrating MLI
900. keV	maximum energy for electrons penetrating MLI
4.0	dielectric constant
5.0 mm	thickness of wire insulation
100. cm	length of exposed wire
100. cm	width of expose wire
$10^{18} \Omega \cdot m$	volume resistivity ($\rho = 1/\sigma$)
1.0	density (not currently implemented)
$10^{-14} / \Omega \cdot m$	radiation induced conductivity (RIC, not currently implemented)
$2.5 \times 10^7 \text{ V/m}$	breakdown strength
1.0	E-field enhancement factor (1=no enhancement, allow sharp points)
0.30	maximum discharge
0.10	minimum discharge
0.1 μ sec	discharge time A
1 μ sec	discharge time B
10 μ sec	discharge time C

Results (2)



Discharges (2)



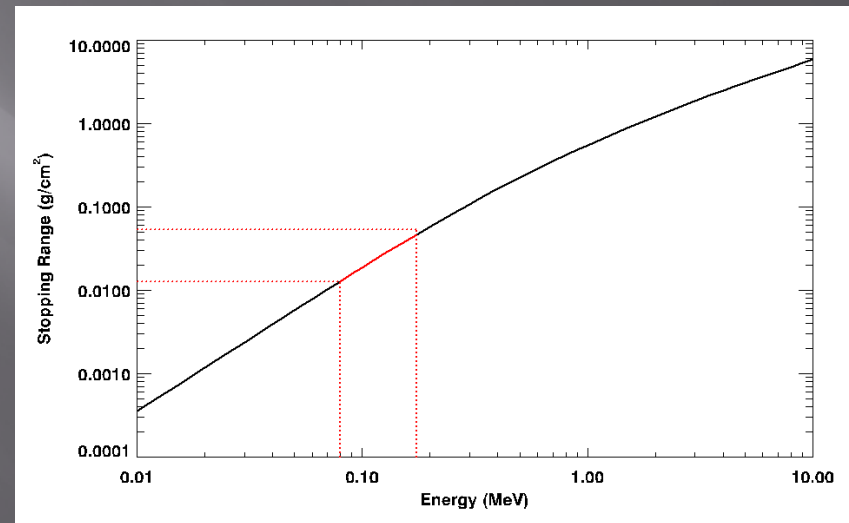
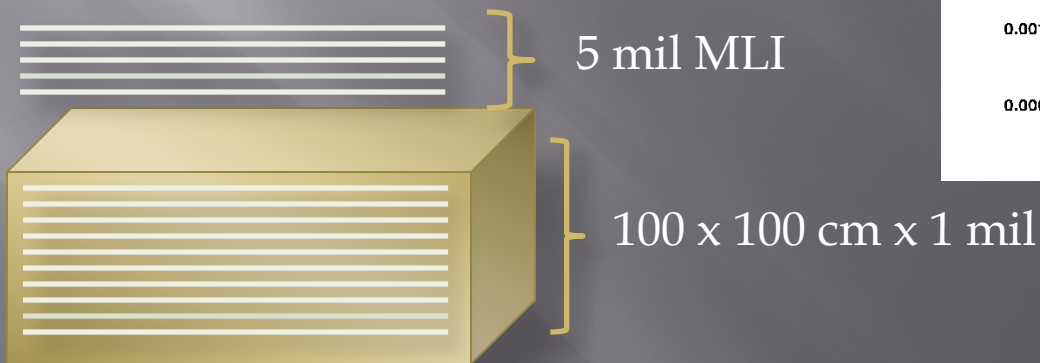
Summary (2)

Arc	Decimal Year (UT)	Day of Year (UT)	Fraction Discharged	Surface Voltage (volts)		Arc Energy (mJoule)	Arc Current (Amp)		
				Before arc	After arc		0.10 μ sec	1.00 μ sec	10.00 μ sec
0	2012.199	73.9777	0.2452	125002.1	94351.6	2.38E+04	2.17E+03	2.17E+02	2.17E+01
1	2012.216	80.074	0.2083	125005.5	98969	20643.57	1.84E+03	1.84E+02	1.84E+01
2	2012.262	96.7142	0.2547	125001.1	93161.1	2.46E+04	2.25E+03	2.25E+02	2.25E+01
3	2012.316	116.7042	0.1557	125005.6	105547.9	15880.62	1.38E+03	1.38E+02	1.38E+01
4	2012.341	125.9564	0.1354	125000.6	108072.8	1.40E+04	1.20E+03	1.20E+02	1.20E+01
5	2012.379	139.7226	0.2789	125000.4	90141.5	26548.62	2.47E+03	2.47E+02	2.47E+01
6	2012.448	165.0763	0.2651	125001.9	91869.4	25436.59	2.35E+03	2.35E+02	2.35E+01
7	2012.501	184.3655	0.1332	125001.2	108348.2	13756.3	1.18E+03	1.18E+02	1.18E+01
8	2012.523	192.2242	0.2149	125009.5	98146.1	21221.3	1.90E+03	1.90E+02	1.90E+01
9	2012.542	199.3705	0.287	125006.1	89129.2	27196.11	2.54E+03	2.54E+02	2.54E+01
10	2012.577	212.2979	0.2316	125001	96049.8	22654.95	2.05E+03	2.05E+02	2.05E+01
11	2012.65	238.959	0.1673	125000.4	104088.7	16958.82	1.48E+03	1.48E+02	1.48E+01
12	2012.697	256.0388	0.1813	125000.1	102333.5	18241.25	1.60E+03	1.60E+02	1.60E+01
13	2012.771	283.19	0.1597	125009.4	105050.2	16254.99	1.41E+03	1.41E+02	1.41E+01
14	2012.783	287.6644	0.2588	125000.6	92647.1	24927.55	2.29E+03	2.29E+02	2.29E+01
15	2012.855	313.9283	0.2144	125001.4	98202.2	21175.1	1.90E+03	1.90E+02	1.90E+01

Simulated: 16 discharges, 26.9 days/event

Example 3

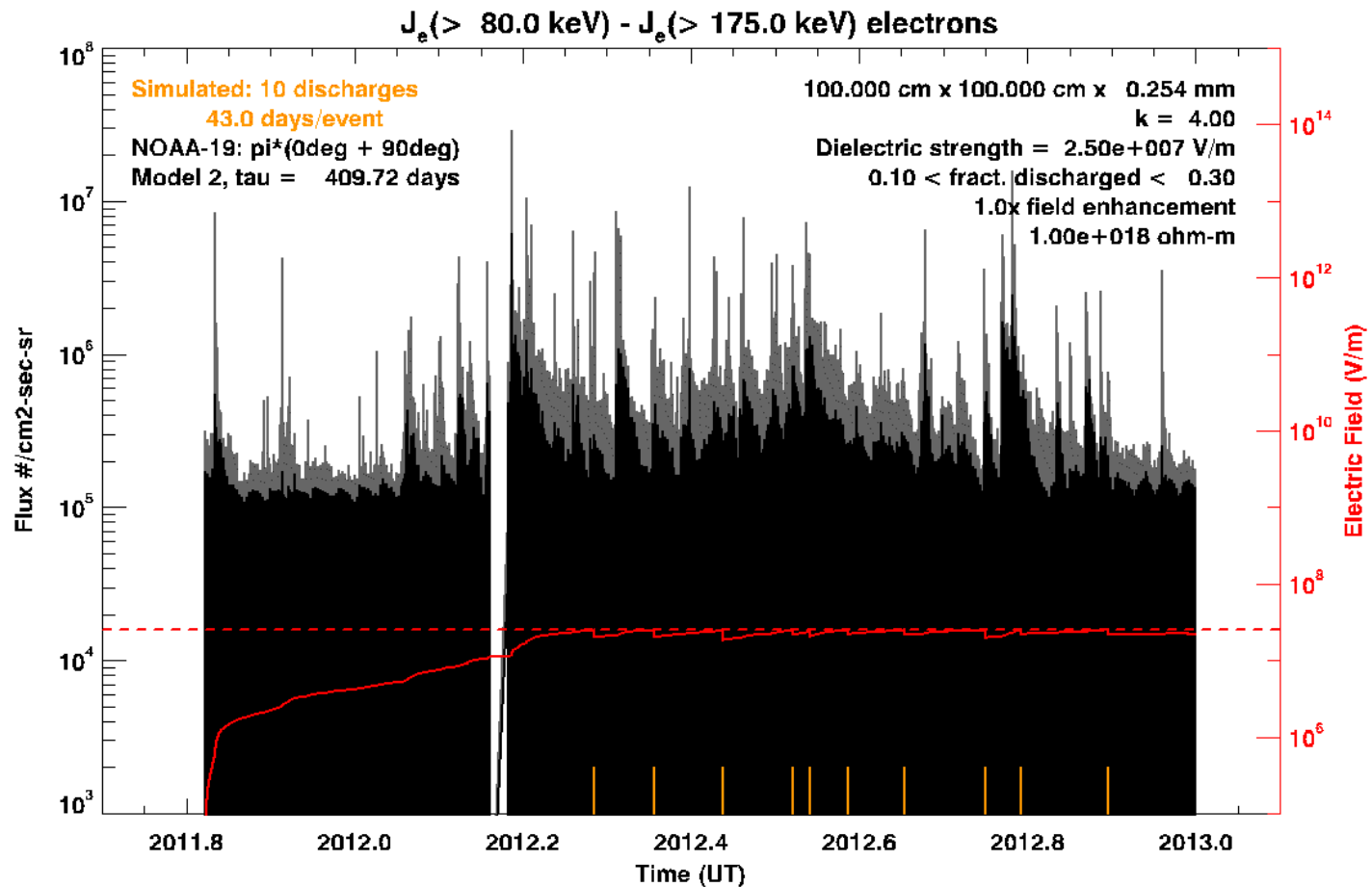
- ▣ Simulates internal charging of 10 mils of ungrounded kapton with 5 mil shielding.
- ▣ Thickness of 0.254 mm



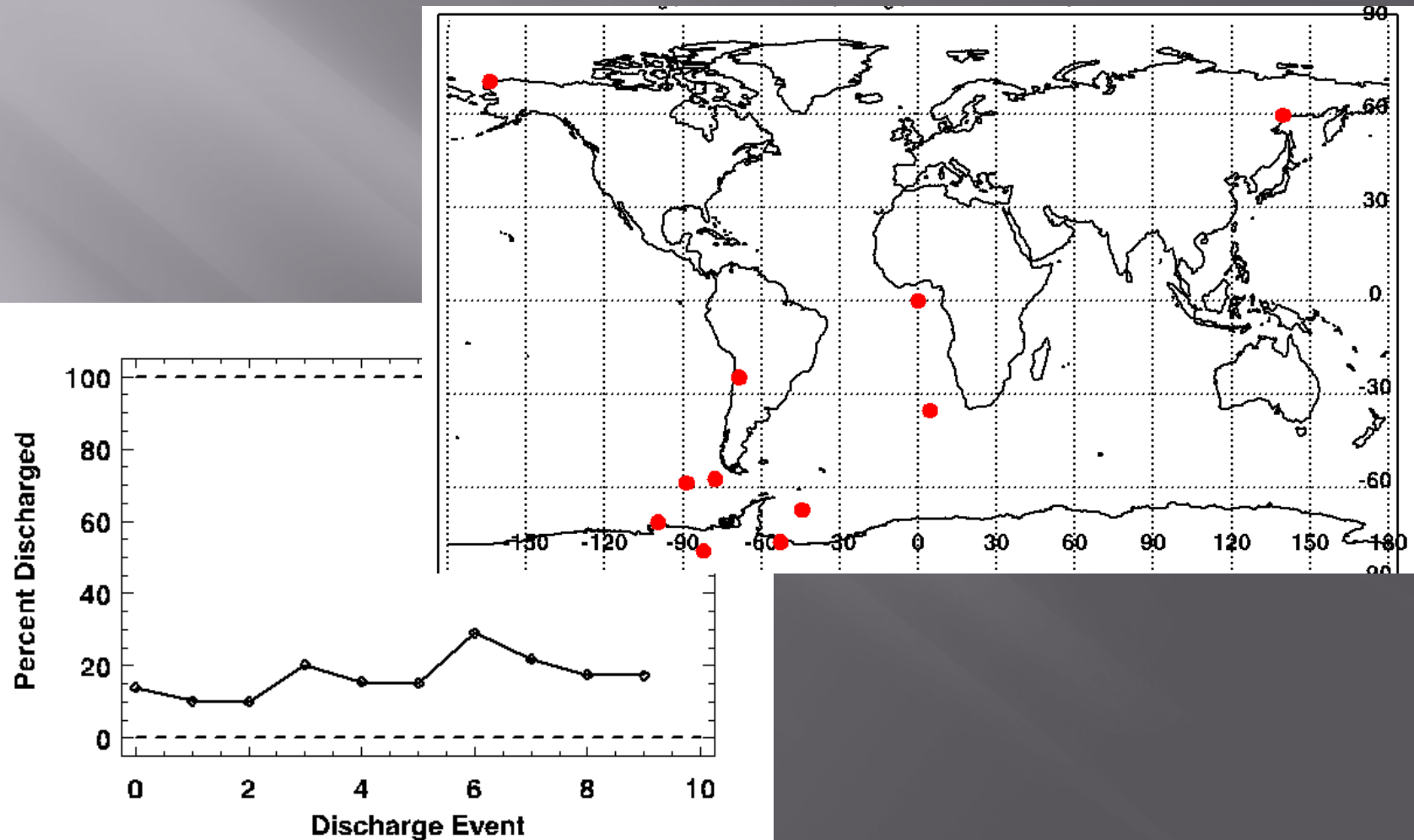
Parameters – Example 3

80. keV	threshold energy for electrons penetrating MLI
175. keV	maximum energy for electrons penetrating MLI
4.0	dielectric constant
0.254 mm	thickness of wire insulation
100. cm	length of exposed wire
100. cm	width of expose wire
$10^{18} \Omega \cdot m$	volume resistivity ($\rho = 1/\sigma$)
1.0	density (not currently implemented)
$10^{-14} / \Omega \cdot m$	radiation induced conductivity (RIC, not currently implemented)
$2.5 \times 10^7 \text{ V/m}$	breakdown strength
1.0	E-field enhancement factor (1=no enhancement, allow sharp points)
0.30	maximum discharge
0.10	minimum discharge
0.1 μ sec	discharge time A
1 μ sec	discharge time B
10 μ sec	discharge time C

Results (3)



Discharges (3)



Summary (3)

Arc	Decimal Year (UT)	Day of Year (UT)	Fraction Discharged	Surface Voltage (volts)		Arc Energy (mJoule)	Arc Current (Amp)		
				Before arc	After arc		0.10 μ sec	1.00 μ sec	10.00 μ sec
0	2012.2844	105.1083	0.202	6350.2	5067.1	1020.793	1.79E+03	1.79E+02	1.79E+01
1	2012.3559	131.2659	0.1964	6350	5102.8	995.4302	1.74E+03	1.74E+02	1.74E+01
2	2012.4373	161.034	0.261	6350	4692.6	1275.369	2.31E+03	2.31E+02	2.31E+01
3	2012.5214	191.8188	0.139	6350	5467.4	726.8035	1.23E+03	1.23E+02	1.23E+01
4	2012.5416	199.2435	0.1778	6350.3	5221.5	910.2372	1.57E+03	1.57E+02	1.57E+01
5	2012.587	215.8513	0.1175	6350.1	5604	621.5244	1.04E+03	1.04E+02	1.04E+01
6	2012.6532	240.0887	0.1344	6350	5496.9	704.3133	1.19E+03	1.19E+02	1.19E+01
7	2012.7506	275.7194	0.2109	6350.2	5010.7	1060.4178	1.87E+03	1.87E+02	1.87E+01
8	2012.7927	291.1283	0.1286	6350	5533.3	676.2808	1.14E+03	1.14E+02	1.14E+01
9	2012.896	328.949	0.1329	6350.1	5506.1	697.2628	1.18E+03	1.18E+02	1.18E+01

Simulated: 10 discharges, 43.0 days/event

Summary

- ▣ Built internal charging model for spacecraft design and anomaly assessment that calculates number of internal discharges given material properties and environment characteristics.
- ▣ As shielding decreases, the number of discharges increases.
- ▣ Ungrounded MLI produced a significant number of discharges even through thin layers.
- ▣ Future Work
 - Additional charging environments
 - Run real time
 - Radiation induced conductivity
 - Density of material
 - Additional capacitance models